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**STUDIES OF DISPLAY SYMBOL LEGIBILITY**

Part IV. The Effects of Brightness, Letter Spacing, Symbol  
Background Relation and Surround Brightness on the Legibility  
of Capital Letters

MAY 1966

D. Shurtleff  
B. Botha  
M. Young

Prepared for

DEPUTY FOR ENGINEERING AND TECHNOLOGY  
DECISION SCIENCES LABORATORY  
ELECTRONIC SYSTEMS DIVISION  
AIR FORCE SYSTEMS COMMAND  
UNITED STATES AIR FORCE  
L. G. Hanscom Field, Bedford, Massachusetts



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**Project 7030**

Prepared by

THE MITRE CORPORATION

Bedford, Massachusetts

Contract AF19(628)-5165

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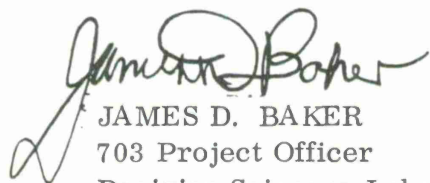
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## FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; and "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966.

## REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.



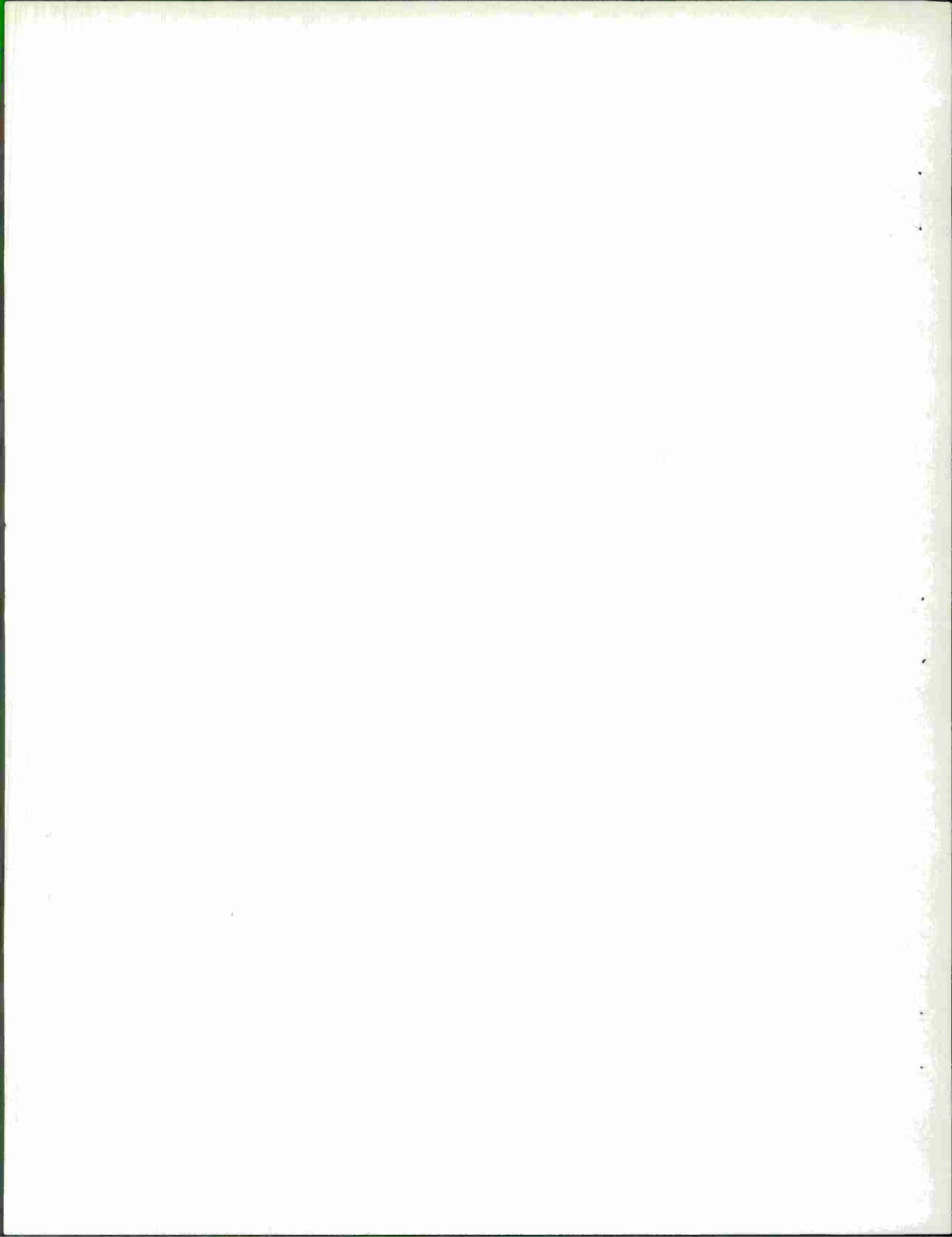
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## ABSTRACT

Two exploratory studies are reported in which the effects of brightness, letter spacing, symbol background relation, and surround brightness on legibility were determined. As a measure of legibility, both studies used the reciprocal of the visual angle subtended at the eye by capital letters when the subject identified correctly 50 percent of the letters in a matrix. A matrix consisted of 20 letters arranged in 4 rows and 5 columns. The first study showed that legibility was significantly altered by brightness, spacing, and symbol background relations. The complexity of the effects of each of these factors was shown by the significant interactions among them. The second study showed surround brightness for the light letters on a dark background to be significant factor in legibility.



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# SECTION I

## EFFECTS OF BRIGHTNESS, SPACING, AND SYMBOL BACKGROUND RELATION

### PROCEDURE

Two subjects with normal vision were required to identify letters arranged in a matrix of four rows and five columns. Initially, each matrix was placed at a distance for which only a small percentage of the letters were identifiable. Subsequently, the matrix was moved closer to the subject, in increments of 6 inches, until he made three readings of the matrix with less than 50 percent of his letter identifications in error. The subject read the matrices with brightnesses of 1, 20, and 40 foot-lamberts (ft-L), with letter spacings of 25 and 200 percent of letter height, and with light letters on a dark background (L/D), and dark letters on a light background (D/L). In a total of 48 sessions, each subject read four different matrices for a given set of conditions (one brightness, one symbol background relation, and one spacing).

### Experiment Situation

The major features of the experiment situation included: (a) the use of three sets of baffles so that brightness could be controlled throughout most of the visual field (Figures 1 and 2); (b) a brightness of the task-surround area which was very nearly the same as that of the task-background area (see Figure 2); and (c) a contrast value of 0.94-0.95 for each of the three values of brightness and for each of the two symbol-background relations (L/D and D/L).

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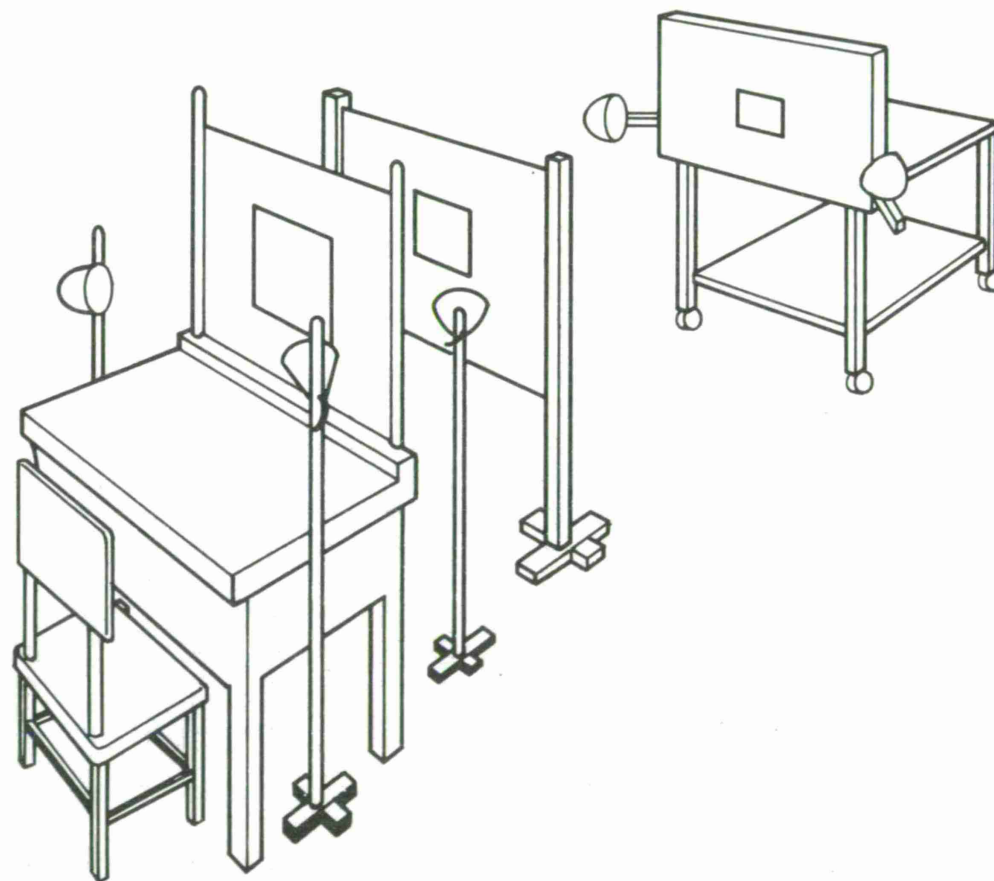


Figure 1. Subject's Station in Relation to the Three Sets of Baffles.  
Moveable Trolley Contained the Letter Matrices.

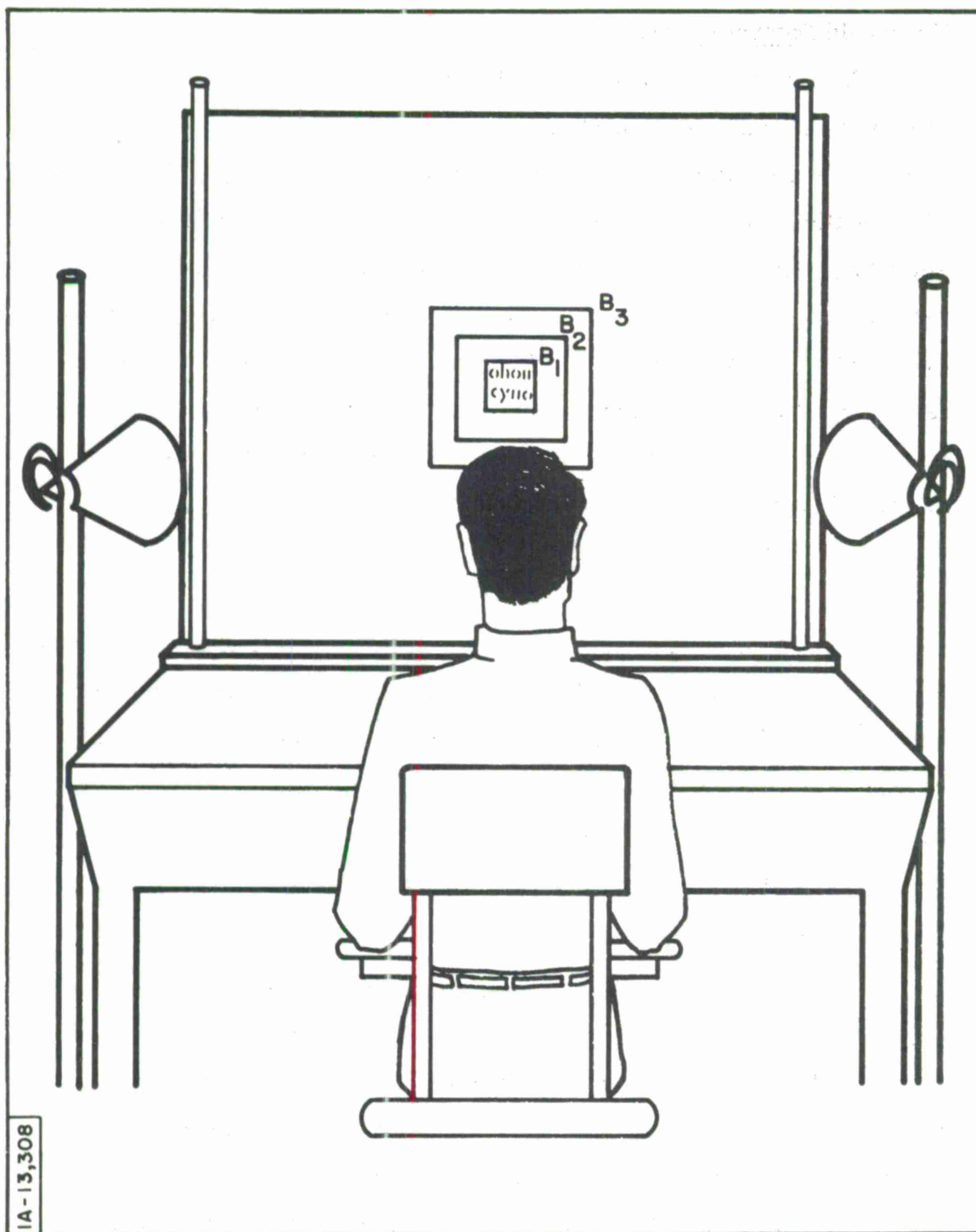


Figure 2. Subject's View of the Letter Matrices. ( $B_1$  is the Task-Background Area Subtended at an Angle of  $15^\circ$ ;  $B_2$  and  $B_3$  are Task-Background Areas Subtended at  $60^\circ$ .)

### Threshold Determinations

The order of threshold determinations was arranged so that practice effects were counter-balanced over the experimental conditions. For a given set of conditions, half of the thresholds were based upon the subject's identifications of letters presented upside down, and half for letters presented right-side-up, in order that the subject would be less likely to memorize the letter sequences. (The data indicated that letter orientation did not affect the thresholds, and the results are based upon both kinds of letter identifications.) Also, the subject was never allowed to score 100 percent correct identification of the letters in a matrix, which provided an additional guard against the memorization of the matrices.

### RESULTS

The individual acuity scores are presented in Table I and the average acuity scores are plotted in Figure 3. Table I shows that the two subjects achieved a high degree of similarity between their acuity scores. These scores represent the reciprocal of the visual angle subtended by the letter height at the eye when the subject was able to identify correctly 50 percent of the letters in a matrix. The 50-percent point was estimated by a method of graphic interpolation.

Figure 3 shows that: (a) increasing the brightness from 20 to 40 foot-lamberts had little effect on acuity, while increasing the brightness from 1 to 20 foot-lamberts had a marked effect on acuity; (b) symbol background relation and letter spacing did not affect acuity at 1 foot-lambert, but at 20 and 40 foot-lamberts, the 200-percent spacing yielded higher acuity scores than did 25-percent spacing; (c) dark letters on a light background gave a better average acuity score than light letters on a dark background;

Table I  
Reciprocal of the Visual Angle  
(Two Values of Symbol Background Relation, Two  
Values of Spacing, and Three Values of Brightness)

Subjects	Spacing %	Dark on Light Brightness (ft-lambert)			Light on Dark Brightness (ft-lambert)		
		1	20	40	1	20	40
1	25	0.30	0.39	0.40	0.30	0.31	0.31
2	25	0.30	0.40	0.40	0.29	0.32	0.33
1	200	0.32	0.44	0.44	0.31	0.40	0.39
2	200	0.31	0.44	0.45	0.31	0.41	0.42

and (d) the wider letter spacing produced a greater increase in acuity for light letters on a dark background than for dark letters on a light background.

The data shown in Table I were submitted to an analysis of variance, and the results are presented in Table II. In Table II, all main effects were significant except those for the subjects. All first- and second-order interactions were significant except those involving the subjects.

## DISCUSSION

### Acuity and Brightness

The relationships between acuity and brightness shown in the present study are in agreement with some data previously reported by Cobb and

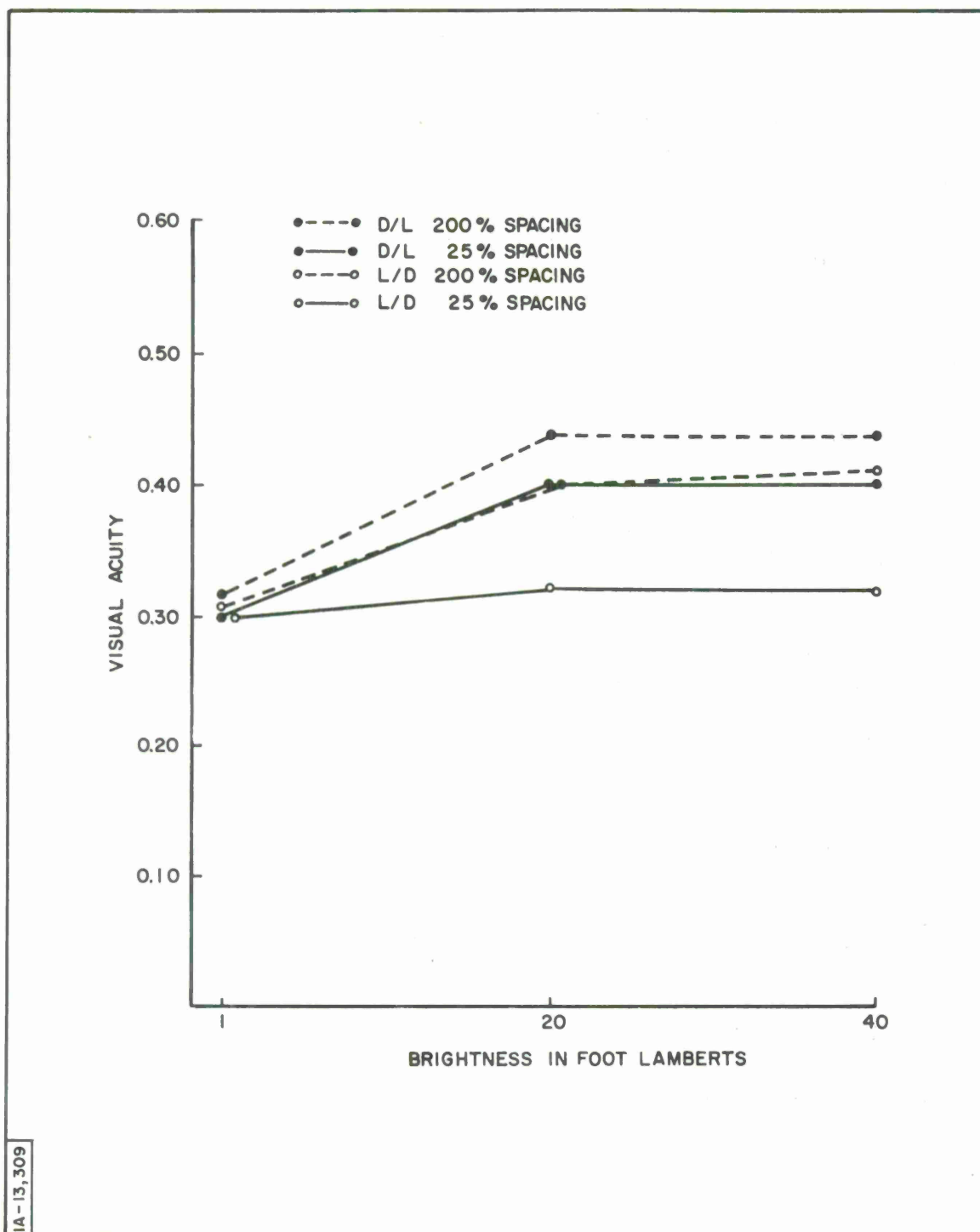


Figure 3. Acuity Data for Two Values of Letter Spacing and Symbol Background Relations and Three Values of Brightness.

Table II  
Analysis of Variance of Acuity Data

Source of Variance	Sum of Squares	df	Mean Square	F	P
Brightness (B)	391.6	2	195.8	1305.3	0.01
Spacing (S)	145.1	1	145.1	967.3	0.01
Symbol Background (SB)	100.1	1	100.1	667.3	0.01
Subjects (Sub)	2.1	1	2.1	14.0	NS
B x S	35.1	2	17.6	117.3	0.01
B x SB	38.5	2	19.2	128.0	0.01
B x Sub	4.1	2	2.0	13.3	NS
S x SB	12.0	1	12.0	80.0	0.05
S x Sub	0.0	1	--	--	--
SB x Sub	1.0	1	1.0	6.6	NS
B x S x SB	6.1	2	3.0	20.0	0.05
B x S x Sub	0.5	2	0.2	1.3	NS
B x SB x Sub	1.1	2	0.6	3.8	NS
S x SB x Sub	0.4	1	0.4	2.7	NS
B x S x SB x Sub	0.3	2	0.15		
Total	738.0	23			

Moss.<sup>[1]</sup> The Cobb data indicated that when contrast\* is high, increased brightness from 0.09 to 18 foot-lamberts yielded a larger increase in

\* The formula used to determine contrast was

$$C = B_s - B_b / B',$$

where

C = contrast,

$B_s$  = symbol brightness (ft-L),

$B_b$  = background brightness (ft-L), and

$B'$  = the brighter of the two ( $B_s$  or  $B_b$ ), (ft-L).

acuity than a change in brightness from 18 to 93 foot-lamberts. An extrapolation from the Cobb data suggests that there should be very little increase in acuity when brightness is increased from 20 to 40 foot-lamberts. The data from the present study supports this extrapolation. Moreover, the Cobb data suggest that when contrast is high, the relationship between acuity and brightness is a negatively accelerated increasing function and that acuity will not increase very much for brightnesses in excess of 100 foot-lamberts. In fact, when contrast is high, acuity at 100 foot-lamberts is nearly as good as that for brightnesses of up to 1000 foot-lamberts.

The present finding that letter spacing had little effect on acuity at the lowest brightness is consistent with the results of a study by Crook.<sup>[2]</sup> Crook found no significant difference in recognition time between spacings of 5.4 and 16.2 percent of numeral height at a brightness of 0.01 foot-lambert. His data showed that, in most cases, recognition time was faster for the wider spacing. The data from the present report suggests that spacing will have a more pronounced effect on acuity for brightnesses above 1 foot-lambert and, perhaps, only for a much wider range of spacings than that used by Crook.

#### Acuity Investigations

Previous investigations of acuity for D/L versus L/D relations are inconclusive; some show L/D to be better, and others show D/L to be better. Apparently, the outcome of studies concerned with this relation are highly dependent upon the nature of conditions existing at the time the measurement is made.

Some of the factors which might be expected to affect the outcome of a study of symbol-background relations are indicated by the results of the present report; namely, (a) the brightness under which the measures are

made (these may be crucial since at low brightness no difference would be found, while at the higher brightnesses a difference in favor of D/L letters would be found), and (b) spacing, or the proximity of borders, which may affect the magnitude of the differences between L/D and D/L since the present data indicates that narrow spacing will lead to a bigger difference in acuity between the two than will wider spacing.

Section II indicates an additional factor which may be responsible for some of the inconsistencies among studies concerned with the dark-on-light versus light-on-dark problem.

## SECTION II

### EFFECTS OF SURROUND BRIGHTNESS ON LEGIBILITY

#### INTRODUCTION

An analysis of the experimental situation in Section I suggested that part of the difference in acuity between light letters on a dark background (L/D) and dark letters on a light background (D/L) could have been caused by the disparity in brightness of the task-surround area (Figure 2). The brightness of the task-surround area for the D/L situation was much greater than for the L/D situation, and evidence in the literature shows that changes in the brightness of the task-surround area, in a D/L situation, affect acuity.<sup>[1]</sup> The majority of studies in this area have shown that the brightness of the task-surround area used in Section I for the D/L situation is optimal for the best acuity. There are no corresponding studies in the literature which indicate what the optimal surround brightness should be for a L/D situation.\* Part of the differences in acuity between the two symbol background relations may have been produced by an optimal brightness of the task-surround area for the D/L situation and a non-optimal brightness of the task-surround area for the

---

\* Because of the failure in the literature to distinguish between L/D and D/L situations in statements about the relationship between acuity and the brightness of the task-surround area, it was assumed by the authors that the same relationship applied to both symbol-background situations. For this reason the task-surround area was set at a brightness equal to that of the task-background area for both the L/D and D/L situation, because the literature indicated that uniform brightness between these two areas leads to optimal acuity for the values of brightness used in the present study.

L/D situation. This experiment was conducted to determine if acuity was affected by changes in the brightness of the task-surround area in a L/D situation.

## PROCEDURE

The second experiment was similar to the first with the exception that only light letters on a dark background were used. Three subjects\* with normal vision read letter matrices which were similar in all respects to those in Section I, with the one exception that the letters in the matrix were spaced at a distance of 100 percent of letter height. Furthermore, because no differences between 20 and 40 foot-lamberts were evident in the first study, only two values of brightness were used in the present study; namely, 1 and 40 foot-lamberts. In addition to the two values of letter brightness, two values of brightness of the task-surround area were included. One brightness of the task surround was the same as that for the task background, while the other brightness of the task surround was equal to that of the letter (Figure 2).

Each subject made four readings in sixteen sessions for each combination of conditions - one value of brightness of the task-surround area and one value of letter brightness.

## RESULTS

The average acuity scores are shown in Figure 4, and the individual acuity scores for each subject are presented in Table III. Figure 4 indicates

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\* One subject served in both experiments so that it was possible to determine for this one subject whether letter spacing 100 percent of height was as effective as letter spacing 200 percent of height in increasing visual acuity.

Table III  
Reciprocal of Visual Angle in Minutes (Two Values of Letter  
Brightness and Two Values of Surround Brightness)

Slide Subject	Symbol Brightness			
	1 ft. -lambert		40 ft. -lamberts	
	Surround Bright. Equal to Symbol	Surround Bright. Equal to Task Background	Surround Bright. Equal to Symbol	Surround Bright. Equal to Task Background
A	1 0.20	0.22	0.29	0.24
	2 0.22	0.23	0.29	0.23
	3 0.30	0.29	0.41	0.32
B	1 0.19	0.22	0.31	0.31
	2 0.25	0.23	0.32	0.33
	3 0.30	0.30	0.41	0.41
C	1 0.22	0.25	0.31	0.29
	2 0.25	0.31	0.39	0.29
	3 0.31	0.31	0.43	0.41

that, at a letter brightness of 1 foot-lambert, the brightness of the task-surround area had little effect on acuity. However, at a letter brightness of 40 foot-lamberts, acuity was better when the brightness of the task-surround area matched that of the letters than when the brightness of the task-surround area matched that of the task-background. An analysis of variance of these data indicated that the main effect of the brightness of the task-surround area was not a significant source of variance, but that the interaction between brightness of the task surround and letter brightness was significant (Table IV). These findings are in agreement with data shown in Figure 4, and indicate that changes in the brightness of the task

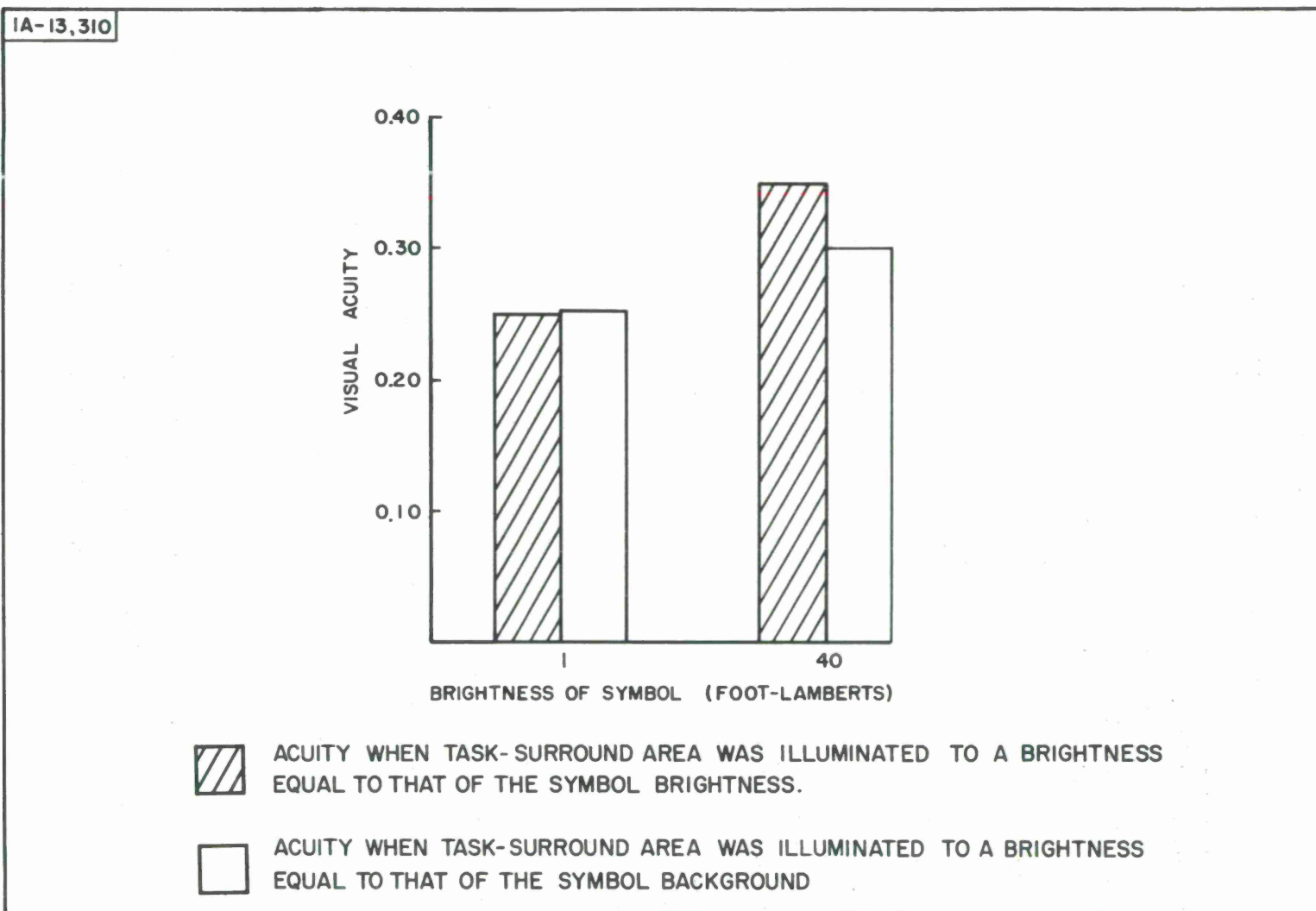


Figure 4. Average Acuity Scores.

Table IV  
Analysis of Variance of Acuity Data

Source of Variance	SS	df	MS	F	P
Surround Brightness (SB)	12.2	1	12.2	1.8	NS
Letter Brightness (LB)	536.7	1	536.7	77.8	0.01
Slides (S)	120.2	2	60.1	8.7	0.05
Subjects (Sub)	596.2	2	298.1	43.2	0.01
SB x LB	56.2	1	56.2	8.2	0.05
SB x S	17.2	2	8.6	1.2	NS
SB x Sub	8.2	2	4.1	--	--
LB x S	32.7	2	16.4	2.4	NS
LB x Sub	20.4	2	10.2	1.5	NS
S x Sub	16.7	4	4.2	--	--
SB x LB x S	28.2	2	14.1	2.0	NS
SB x LB x Sub	4.2	2	2.1	--	--
SB x S x Sub	3.7	4	1.0	--	--
LB x S x Sub	4.4	4	1.1	--	--
SB x LB x S x Sub	27.7	4	6.9		
Total	1484.8	35			

surround affected acuity only at the higher letter brightness, and not at the lower letter brightness.

A comparison of the acuity scores for the one subject who served in both studies indicated that acuity for the 100-percent spacing was as good as acuity for the 200-percent letter spacing.

#### DISCUSSION

The results of the experiment indicate that the measures of acuity for the light-on-dark situation in Section I, were not taken with an optimal brightness of the task surround. In fact, it is interesting to note that the

brighter task surround increased acuity by an amount that was approximately the same as the average difference found between D/L and L/D conditions in the first experiment at brightnesses of 20 and 40 foot-lamberts. Therefore, it is probable that the use of the brighter task-surround would have eliminated the difference in acuity between D/L and L/D at the wider spacing and at brightnesses of 20 and 40 foot-lamberts.

Both studies together suggest that there should be no differences in acuity between the two symbol-background relations if

- (a) letters with high contrast are used,
- (b) the measurement is taken under the conditions of wide spacing and brightness of 20 to 40 foot-lamberts,
- (c) the brightness of task-surround area is the same in both the D/L and L/D situations.

#### Illumination Variations

The effects of variations in the illumination of the task surround on acuity in a D/L situation are understood better than in a L/D situation. Although the results are not conclusive, it appears that when the task-surround illumination in a D/L situation is varied from darkness to a brightness equal to that of the task background (Figure 2), a task surround dimmer than the task background is optimal when the task background is less than 1 foot-lambert. A task-surround brightness equal to the brightness of the task background is optimal for the task-background brightness in excess of 10 foot-lamberts. At the higher task-background brightnesses (10 foot-lamberts and above), there is some indication that acuity will decrease gradually as the brightness of the task-surround area is made dimmer than that of the task background. Acuity will deteriorate rapidly when the task-surround is made brighter than the task-background<sup>[3]</sup>.

### Light-Dark Relationships

The impression that the same sets of relations are also descriptive of a situation involving light letters on a dark background is given. Although the results of the present study are only suggestive, it is reasonable to propose that a different set of relationships exists in a L/D situation. The hypothesis suggested by the present data is that, when letter illumination is 10 foot-lamberts or above, acuity should gradually improve as the brightness of the task surround is increased until it is as bright as the object discriminated (rather than as bright as the task-background which was the case with dark objects on a light background). With further increases in brightness of the task surround, acuity should deteriorate.

The hypothesis is only partially supported by the present data and must be verified by a study of a greater number of brightnesses of the task surround before generalizations are permissible. In view of the current popularity of displays consisting of light objects on a dark background in variously lighted rooms, the suggested relationship seems to be worth a more detailed examination.

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3. P. Moon, The Scientific Basis of Illuminating Engineering, Dover Publications, Inc., New York, 1961, pp. 440-450.

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